Investigating the Relationship Between Exoskeleton Designers and their Users

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

In a study of epidemiologic data of 30 individual neuromuscular disorders spanning over 150 reported studies, the prevalence of neuromuscular disorders as a group is 100-300 per every 100,000 people (Deenen et al., 2015). The impact of these disorders is profound, as it makes everyday tasks such as walking, climbing up stairs, and lifting small objects challenging. This can affect both the physical and emotional qualities of life. These neurological injuries do not have a cure, placing immense pressure on engineers to create devices that can help patients regain functionality (Gorgey, 2018). Exoskeletons have recently emerged as a promising technology that has the potential to allow people with limited mobility to utilize their joints and boost their strength. They have proved to be vital technologies in the medical field for helping patients navigate rehabilitation and daily activities of living. Not only have exoskeletons been designed for medical purposes, but they have also been integrated into the workplace for injury prevention and the military for added strength. In the workplace, lifting tasks account for 30% of total workplace injuries, and exoskeletons have been identified as a potential solution to alleviate the burden on workers' joints, reducing total injuries (Howard et al., 2019). The versatility of exoskeletons has made them a significant tool for enhancing human mobility and strength in many industries.

Although exoskeletons have proved to restore limb functionality and have promising results with injury prevention, their use has been very limited in society due to adoption barriers. According to a study performed with wearable robotics for Spinal Cord Injuries (SCI), there have been improvements in "performance, such as balance, walking distance, velocity, and duration." However, only a small number of patients choose to use these devices because they can be challenging to use and present many risks (Forte et al., 2022). Similarly, industrial exoskeletons have many benefits, such as productivity gains, the elimination of physical fatigue and workplace injuries, and a reduction of risk factors with overhead tasks. However, the same adoption barriers persist in the workplace with workers expressing concerns about hygiene, the risks for pressure wounds from prolonged use, and lack of safety measures (Howard et al., 2019).

There are many risks and challenges associated with designing exoskeletons due to the design and testing parameters weighing heavily on the targeted user. This makes it difficult to create a one-size-fits-all design due to the diversity of potential users and variability of intended tasks. The integration of different sensors, actuators, mechanical designs, and feedback controls further complicates the design process, making it difficult to compare designs and create standardized testing metrics. Currently, performance standards are still being developed for exoskeletons, because pre-existing industrial robotic metrics do not typically include humans. This makes it challenging to access performance data when designing exoskeletons (Bostelman & Hong, 2018). Due to a lack of universal testing metrics, each study performs varying levels of objective and subjective testing. Objective testing evaluates the functionality of the sensors and the psychological responses, whereas subjective testing evaluates user feedback and the ergonomics of the system (Zheng et al., 2021). The lack of testing metrics has made it difficult for designers to obtain substantial user feedback to improve their designs.

Despite the promise that exoskeletons have shown for limb assistance in the medical industry and injury prevention in the workplace, the lack of standardized testing metrics has led to a disconnect between designers and users, causing adoption barriers that have severely impacted the acceptance of these technologies into society. This argument will be supported through a literature review and an analysis. The literature review examines the development of exoskeletons over time, existing testing metrics, and design challenges that have led to a disconnect between users and designers. Due to exoskeletons being a relatively new field, the data is limited due to a lack of tangible test subjects, so I gathered data mainly through a literary analysis and policy analysis for my analysis section. My analysis uncovers that exoskeletons are not meeting user needs, as supported by the findings of subjective analyses which have uncovered concerns with safety, ease of use, and cost. This has led to distrust with commercially available designs, despite the objective analysis findings that highlight benefits such as medical patients regaining limb functionality and industrial workers experiencing less force on their joints.

Literature review

The exoskeleton designs have varying parameters and performance standards that they follow. In September of 2017, 40 participants from different industries including the military, exoskeleton manufacturers, user groups, and laboratories came together to create new exoskeleton standards, known as the ASTM International Committee F48 on Exoskeletons and Exosuits. Subcommittees developed standards for safety and quality, and separated them into four sectors: industrial, medical, military, and consumer (Lowe et al., 2019). However, one main challenge remaining is that there are no established test methods and certifications, causing a large variation in the way exoskeletons are tested (Lowe et al., 2019). The differing test methods make it very challenging for the designers to properly evaluate the consequences of the devices that they create. Furthermore, the comfortability level has not been qualified yet, leading to discrepancies amongst subjective tests. It is difficult to access the ergonomics and ease of use of the exoskeletons, because comfortability is not something that is addressed by preexisting industrial robots (Bostelman & Hong, 2018). This makes it challenging to access how safety should be quantified.

Other wearable technologies in the biomedical field, such as biosensors, that have well-established standards, have gained wider acceptance among their users. Biosensors are a type of wearable electronics used widely in the medical field for general healthcare monitoring, diagnosis of diseases, and clinical analyses (Mandal, 2019). They typically include two main components: a bioreceptor that recognizes analytes such as enzymes, cells, deoxyribonucleic acid (DNA), and antibodies and an electrical transducer that converts the data from the bioreceptor to a measurable signal. Some of the standards that biosensors are upheld to are selectivity, reproducibility, and sensitivity. Selectivity is the ability to detect the analyte, reproducibility is the ability generate the same responses under the same conditions, and sensitivity is the ability to accurately measure the analyte (Bhalla et al., 2016). Due to established standards, biosensors have been integrated commercially and brought a new platform for health monitoring. Their real time data and accuracy as established by testing metrics allows for improved clinical decisions, improving the efficiency of health systems. As of 2021, the global biosensor market was valued at 25.5 billion USD, and it is expected to grow 7.5%, reaching 36.7 billion USD by 2026 (The Worldwide Biosensors Industry, 2021). The medical field accounts for 78% of the market, displaying how they've been widely accepted by medical patients (Nan et al., 2022). Biosensors have been able to successfully grow commercially, displaying how standardized evaluation procedures are effective with gaining the acceptance of their users.

There have been studies carried out to elicit user feedback on exoskeletons to create a standardized method of testing and proposed solutions to incorporate feedback into designs. In a study published by Prosthetics and Orthotics International, six clinicians from the Glenrose

Rehabilitation Hospital and eight users with impaired hand functions were interviewed to determine the functionality of an existing hand exoskeleton and gain user feedback on concerns that they had. Some of the user's concerns brought up during the study were comfortability, cleanliness, and the desire to use the device independently without additional assistance (Boser et al., 2021). The designers were able to use the user feedback to improve their design. Similarly, there was mixed initiative learning approach developed in 2020 call the CoSpar Algorithm that targeted lower body exoskeletons that aims to create a standardized method of testing. The steps it proposes are to draw samples from the users, analyze the data, and ask for users' feedback in between each trial. The user is also able to suggest improvements for the design during the trials as well (Tucker, 2020). The experiment was performed with three able-bodied users, and CoStar was able to model their preferences successfully, demonstrating a working testing technique (Tucker, 2020). While there have been no standardized testing techniques for exoskeletons established yet, it is clear the different groups are attempting to do so.

The two theoretical frameworks I will be using are configuring the user by Woolgar (1990) and design justice by Costanza Chock (2022). Configuring the user explores the idea of a machine being a text that is set to 'configure' the user. The designers set constraints upon their intended users likely future actions (Woolgar, 1990). I will be using this framework to analyze how designers have set testing requirements and performance standards to 'configure' their users and limit how their products are used. This will uncover the disconnect between the designer's presumptions of their users and what the users are seeking out in their products, as revealed by subjective testing. Design justice investigates the relationship between design, power, and social justice and describes how universal design principles can erase certain groups of society. I will be using this framework to analyze the impact of exoskeletons on different groups in society and lay down a framework for standardized metrics and testing that will focus on empowering their users, instead of erasing them. I will use both frameworks to compare the intended impact of exoskeleton designs and their actual impact as determined by the users.

Methods

Because the field of exoskeletons is relatively novel, I will mainly use secondary sources for my research through a literary analysis and policy analysis. I will focus on finding academic journal articles on the design process, adoption barriers, risks and benefits, and history of exoskeletons. The scope of my research will be limited to designers of medical and industrial exoskeletons and their users. I will focus my research on marginalized communities such as the disability community and their usage with medical exoskeletons and will consider the concerns of workers that use industrial exoskeletons.

Analysis

User Concerns About the Extended Use of Exoskeletons

The findings of subjective evaluations in the medical field have displayed that one of the main adoption barriers preventing exoskeletons from being accepted by their users is safety. Rigid exoskeletons especially have caused great concerns in the medical field despite the success of commercially available designs made by Rewalk, Ekso, Indego and more. These designs are more traditional and have showed great improvements with SCI patients being able to walk, increasing their strength, and gaining control of their posture (Morris et al., 2023). However, they come with disadvantages due to the uncomfortability of the rigid structures. According to research done by the Wyss Institute, devices that are rigid can “impede a wearers’ natural joint movements, thus causing fatigue and exacerbating the very problems they are attempting to fix" for people with less severe mobility issues (Wyss Institute, 2019). Most of the devices that are commercially available are rigid, creating a large safety concern about whether the user will experience significant muscle strain and fatigue due to the device moving beyond the range of desired motion. Furthermore, patients suffering from neuromuscular diseases can experience symptoms of muscle twitches and spasms (Cedars Sinai, n.d.). This has led to patient anxiety around how the device would respond to atypical muscle reactions. If the exoskeleton is not able to fully grasp user intention due to the sensors reading in unexpected data, immense strain and fatigue can occur (Morris et al., 2023). While some exoskeleton designers have successfully created designs that enhance user strength, their focus on improving the users physical state may not align with the users' concerns with safety and comfort. As a result, there is a significant disconnect which limits the widespread use of these devices in everyday life.

Similarly in the workplace, subjective evaluations have found that the main safety concern is centered around the load of the device. A study involving eight industrial workers using an upper limb exoskeleton for overhead tasks found that the exoskeleton did not reduce the total load on their joints as intended. Instead, it shifted the load for their shoulders to their legs and lower back (Howard et al., 2019). This is a huge concern because this can lead to lower back pain, contributing to one of the most prevalent problems in the working industry. Lower back pain "represents a high economic burden, affecting 75–85% of workers at some point in their lifetime" (Baltrusch et al., 2020). Designers should focus on creating designs that reduce the total burden on the workers to ensure that their lower back pain isn't amplified and turned into a greater issue in the long run. Although some designs like SPEXOR, a passive trunk exoskeleton, have shown significantly reduce lower discomfort in the back during tasks of lifting, bending, and kneeling, this is not the case for all exoskeletons (Baltrusch et al., 2020). This displays that there is a lack of standards for ergonomics, leading to some designers neglecting the additional loads on their users in the designs that they create.

Exoskeletons typically require a lengthy training period and a complicated method of putting the device on, causing users to stray away from using them in their daily lives. Misalignment is a very pressing issue because it can cause extraneous forces on the users' joints, requiring many designs to have very detailed procedures and lengthy sessions to ensure a proper fit (Gull et al., 2020). Although it is important to ensure that misalignment doesn't occur, the lengthy sessions can pose an inconvenience to the user and the physiotherapist, making it difficult to integrate exoskeletons into a daily routine. A typical stroke survivor receives 45 minutes of therapy everyday (Morris et al., 2023). In a study with an exoskeleton used for gait rehabilitation with stroke survivors in 2020, it took the patients approximately 30 to 40 minutes to properly align the device, which could take a significant cut out of their regularly scheduled sessions (Vaughan-Graham et al., 2020). This shows that a stroke survivor would have to double the time of their regular session to ensure that they can fit the device and still meet the recommended therapy time. This extended fitting time could increase the cost and time spent on therapy, potentially detering users. While exoskeleton designers are focused on ensuring misalignment does not occur, they should also consider developing devices that are more user-friendly to align with the users' needs.

The lengthy training periods and complicated methods required for the use of an exoskeleton has affected the physiotherapists that have to monitor the whole process as well. In a study done with 55 physiotherapists where they analyzed an upper limb exoskeleton, it was found through the Likert scale of 1 to 5, where 5 was 'strongly agree', that there was a median score of 4 for questions related to anxiety. This displays that the exoskeletons are taking a toll on those proctoring them and are not the easiest to monitor. Similarly, there was a median score of 2 for the statement, ‘‘I think that using an exoskeleton does not require too much concentration effort on my side’, showing that overseeing the usage of these devices requires immense focus (Luciani et al., 2023). However it has been demonstrated that certain exoskeleton designs are more user-friendly than others, as different designs entail varying procedures, such as taking measurements, fitting parts, and conducting lengthy training sessions, while others do not.A study performed in 2017 with gait rehabilitation found that the patients rated the ease of use of the device a 7.2 out of 10 on the Likert scale where 10 was ‘extremely easy to use’ (Morris et al., 2023). While this shows that all designs aren’t time consuming to fit on, there isn’t a standardized metric put in place detailing how long a patient should have spent fitting the device. This has led to some exoskeletons causing more of an inconvenience than others. If this process was more streamlined, physiotherapists would know what to expect and would be better equipped to help speed up the training sessions.

Measuring the Impact of Exoskeletons on the Disability Community

Measuring effectiveness of exoskeletons is a large problem when dealing with people in the disability community with musculoskeletal or neurological impairment. There hasn’t been a lot of research demonstrating a patient’s progress with the device and without the device. Although, it has been found that these devices have improved range of movement and stability through a Cochrane review of 62 trials with 2400 patients, there is still a lack of standardized outcome evaluations (Morris et al., 2023). Without enough research, the subjective analyses will not be able to be compared to each other, allowing minimal progress to be made with making the devices based off user feedback. Different studies have varying participant sizes, participant age ranges, procedures, and measurements, making it challenging to compare them to each other and quantify user feedback. This is shown through a systematic review that complied data from 42 studies with lower back exoskeletons. Of the 42 studies that were reviewed, only 26 of them performed a subjective analysis which questioned the ergonomics of the product, exhibiting that some designers did not test the comfortability of their design (Golabchi et al., 2022). This is a pressing issue because discomfort was brought up in many of the subjective analyses, and it remained hidden in the studies that solely performed an objective analysis. Furthermore, very few studies utilized both men and women in their experiments, and even if they did, the ratio of men to women was not one to one. For example, the study with the Levitate AIRFRAME used 11 male workers and only 1 female, portraying a sample population that lacked diversity (Golabchi et al., 2022). Through the lens of the design justice framework, we can see that ,“if resource constraints become an excuse to avoid examining the root of the problem area, then designers will almost always end up, at best, providing Band-Aids for deep wounds”. This displays that if designers don’t test their exoskeletons on a diverse group of participants, pressing issues will not get fixed properly (Costanza-Chock, 2022).

Conclusion

The exoskeleton testing metrics that have been put in place do not accurately reflect the needs of their users which has caused distrust, preventing them from being implemented into society. This research matters because it is important to question the benefits of exoskeletons as well as the risks, to accurately measure its impact on the intended users. The design process often excludes the disability community, erasing their needs from technologies. For a technology that is centered around helping their community in the medical industry, it is vital to consider how to allocate the benefits and risks of the technology to better suit their needs. The disconnect between the designers and the disability community has led to severe adoption barriers that have prevented the widespread commercialization of exoskeletons. The previous research and design efforts will be wasted if designers aren’t able to create exoskeletons that users want to use in their daily lives. Designers might read this and change their ways of testing to reflect their users based off the adoption barriers I introduced. Furthermore, organizations like the Institute of Electrical and Electronics Engineers (IEEE) and ASTM International that specialize in creating technology standards can gain insight into the users’ needs.

Most of my research is done with rigid exoskeletons because they are commercially available, however they come with disadvantages due to the weight and strain that they can place on the body. Soft exoskeletons have recently emerged, presenting an alternative, however research is limited on them because they are still in the preliminary design stage. Future research could look more into soft exoskeletons to see if some of the adoption barriers presented by rigid exoskeletons are now eliminated with a device that is more flexible and comfortable. With more research, exoskeleton designers have the potential to revolutionize the medical field and the workplace, creating designs that can make differences in their users lives.

Resources

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